ORDNANCE AND EXPLOSIVES TOOLBOX: SAFETY TECHNOLOGIES FOR OE PROGRAMS

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ABSTRACT

The U.S. Army Engineering and Support Center, Huntsville (USAESCH) is currently engaged in projects which require detection and removal of buried ordnance. The Structural Branch, funded by the Ordnance and Explosives (OE) Innovative Technology Program, has developed several tools for use on OE projects. As these tools are developed, they are submitted to the Department of Defense Explosives Safety Board (DDESB) for approval for use on OE sites. Once a tool has been approved, it may be used on any OE site as long as it is used in a manner consistent with its original development and approval. Use of these tools provides consistency between projects and reduces the paperwork and time needed for review of Explosives Site Safety Plans (ESS).

These tools include methods for calculating fragmentation characteristics, the range to no more than one hazardous fragment per 600 square feet and fragment mitigation using loose fill and sandbags. Hardware developed includes an on-site demilitarization container and several barricades. Software has been developed for several of the calculation methods as well as the Mapping Explosive Safety Hazards (MESH) software.

The various tools that have been developed are presented. The use of each tool is discussed. The approval status of each tool is given.

INTRODUCTION

In November 1997 representatives from the DDESB, each of the armed forces, the U.S. Army Technical Center for Explosives Safety (USATCES) and USAESCH met to discuss standards for Explosives Safety Submissions (ESS). During these discussions USAESCH presented several calculation methods, software and hardware used for OE sites. At this meeting the suggestion was made to submit such standard methods, software and hardware for individual safety approval and create a “tool box” of such methods for use on OE projects. USAESCH has continued to develop such tools and submit them for approval. This paper summarizes the current contents of the OE Toolbox.

Included in the Toolbox are methods for calculating fragmentation characteristics, the range to no more than one hazardous fragment per 600 square feet, and fragment mitigation using loose fill and sandbags. Hardware developed includes an on-site demilitarization container and several barricades. Software has been developed for several of the calculation methods as well as the Mapping Explosive Safety Hazards (MESH) software.

CALCULATION OF FRAGMENTATION CHARACTERISTICS

The tri-service manual, Army TM 5-1300/Navy NAVFAC P-397/Air Force AFR 88-22, Structures to Resist the Effects of Accidental Explosions [1], defines methods for computing the fragmentation characteristics of cased, cylindrical munitions. These characteristics include initial fragment velocity, weight of the largest fragment, average fragment weight, the total number of fragments, and the fragment weight for a given confidence level. These calculated fragmentation characteristics are used for a wide variety of purposes such as determining fragment range, striking energy, fragment density over a given area, and fragment penetration through various target materials.

The TM 5-1300 methods are applicable only for primary fragments resulting from a high-order detonation of a cylindrical cased munition, with evenly distributed explosives in direct contact with the casing. For munitions that are not uniform in case thickness or diameter along the entire length, the casing must be modeled using a series of equivalent cylinders. The method is a trial-and-error procedure involving iterating on geometry to match the total modeled explosive weight to the actual explosive weight.

For example, consider the calculation of fragment characteristics for a 105-mm M1 projectile. The geometric details of this round are shown in Figure 1. This figure also includes the multiple segment cylindrical model for the round. The inner diameter of each segment is selected such that the total weight of the modeled explosive charge equals the total actual explosive weight. The casing thickness is selected to approximate the average actual thickness in each segment. The maximum fragment weights and initial velocities, as computed by the approved methods, are given in Table 1.

Table 1. Selected Fragment Characteristics, 105-mm M1 Projectile

Region	Maximum Fragment Weight (lb)	Initial Fragment Velocity (ft/s)	Maximum Fragment Range (ft)	Hazardous (1/600) Fragment Range (ft)
A	0.206	4055	1939	341
B	0.155	4870	1869	
C	0.086	5175	1590	
D	0.096	4021	1548	

Of particular interest is the ability to compute the maximum fragment range for a particular munition. This distance is important in establishing personnel separation distances (PSD) and public withdrawal distances (PWD) at OE sites. The maximum fragment range is calculated using the maximum fragment weight and velocity for each segment of a modeled round. The range is computed using TRAJ [2], an approved trajectory analysis computer program. For the 105-mm M1 example above, the maximum range for each segment of the model is given in Table 1. The overall maximum fragment range for the round is 1939 feet.

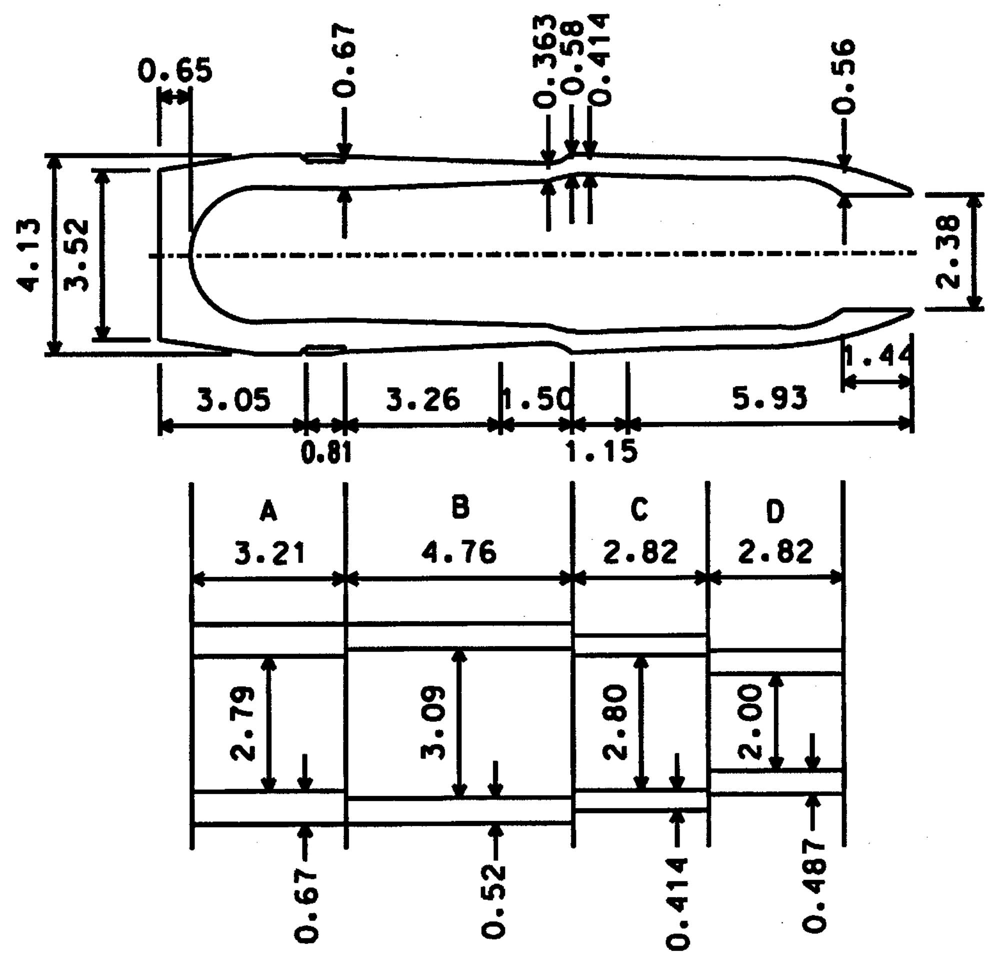

Figure 1. 105-mm M1 Projectile Casing and Model

This primary fragmentation calculations are described in detail in HNC-ED-CS-S-98-1, "Methods for Predicting Primary Fragmentation Characteristics of Cased Explosives" [3]. These methods were approved by the DDESB "for use in deciding Inhabited Building Distance (IBD) for primary fragments in site remediation activities"[1] on April 6, 1998.

CALCULATION OF THE RANGE TO NO MORE THAN ONE HAZARDOUS FRAGMENT PER 600 SQUARE FEET

DOD explosives safety standards, in DOD 6055.9-STD [4], require that persons be protected from being struck by hazardous fragments. A hazardous fragment defined as one with an impact energy of 58 foot-pounds. The DOD standards limit personnel exposures to no more than one hazardous fragment striking an area of 600 square feet.

[1] Text within quotation marks throughout this paper are quotes from the DDESB safety approval memoranda for the approved OE Toolbox items. These memoranda are on file at USAESCH.

USAESCH has developed an analytical method to calculate the range at which the primary fragment density from a cased, cylindrical munition equals one hazardous fragment per 600 square feet. The method is based upon the primary fragmentation distribution model provided in NATO AASTP 1 (AC/258-D/258), <u>NATO Safety Principles for the Storage and Transportation of Ammunition and Explosives</u> [5]. Inputs to this method are the fragmentation data provided by the methods in HNC-ED-CS-S-98-1, described above. Specific inputs include the initial fragment velocity, maximum and average fragment weights, and total number of fragments from each modeled segment of the round, plus an initial assumption of the distance to the 1/600 fragment density. The result is the probability of fragment impact at that assumed distance. A probability of 1 percent occurs at the 1 fragment per 600 square foot, or 1/600, distance. The user iterates on the distance until the 1 percent probability is achieved.

A simple computer program, called HAZFRG, has been developed to perform the 1/600 distance calculations. Input to HAZFRG includes the segmented cylinder model of the round. HAZFRG computes the fragmentation characteristics in accordance with HNC-ED-CS-S-98-1. It then iterates to find the exact distance corresponding to the distribution of one hazardous fragment per 600 square foot area.

HNC-ED-CS-S-98-2, "Method for Calculating Range to No More Than One Hazardous Fragment per 600 Square Feet" [6], details the method used to determine the range to no more than one hazardous fragment per 600 square feet. This report also describes the HAZFRG program. Both the methodology and the program have been validated against the hazardous fragment distances in Table 9-2 of DOD 6055.9. The computed values are conservative relative to the standard. This conservatism is the result of theoretical fragmentation calculations and other conservative assumptions detailed in the report.

The calculation method and the HAZFRG program were approved by the DDESB "for use in deciding Inhabited Building Distance (IBD) for primary fragments in site remediation activities" on April 6, 1998.

FRAGMENT MITIGATION USING EARTH COVER

USAESCH has developed an analytical method to determine the effectiveness of earth or soil cover as a means of mitigating fragments from intentional detonations. The method is based on cratering and fragment penetration through soil as defined in DOE/TIC 11268, "A Manual for the Prediction of Blast and Fragment Loadings on Structures" [7]. The method calculates the required personnel separation distance for fragmentation for buried munition disposal.

Inputs to this method include the maximum fragment weight and initial velocity, as determined by HNC-ED-CS-S-98-1, the soil type and proposed depth of burial. The method includes several steps. First, characteristics of the resulting crater or camouflet are calculated. The velocity of the maximum fragment as it exits the soil is then calculated. The maximum ejecta radius of large soil chunks produced by the cratering are determined using data from DOE/TIC 11268 with an appropriate safety factor. Finally, the maximum fragment distance is computed, again using the trajectory analysis program TRAJ. Either the maximum fragment distance or the soil ejecta radius, whichever is greater, is used as the fragment PSD.

In order to simplify and standardize these calculations, a simple computer program, called the Buried Explosion Module, or BEM, has been developed. Inputs to BEM include the explosive charge weight, depth of burial and soil type, and the maximum fragment weight and initial velocity. The BEM software determines the cratering characteristics, the final fragment velocity, and the maximum soil ejecta radius. Again, the fragment weight and velocity can then be used to determine the maximum fragment range using the TRAJ program.

For example, consider again the 105-mm M1 projectile. The results of burial in various depths wet sandy clay are shown in Table 2. As the depth of burial is increased, the fragment's residual velocity decreases. At a burial depth of 4 feet, the maximum fragment range of 125 feet drops below the soil ejecta distance of 170 feet, so no deeper burial is needed. The 170-foot soil ejecta distance is used as the fragment PSD. If a shorter fragment distance is desired, burial of at least 5 feet must be used. This produces a camouflet, eliminating the soil ejecta and producing a fragment range of just 20 feet.

Table 2. Buried Explosion Results for 105-mm M1 Projectile in Wet Sandy Clay

Depth of Burial (ft)	Crater or Camouflet	Residual Fragment Velocity (ft/s)	Max Soil Ejecta Radius (ft)	Maximum Fragment Range (ft)
3	Crater	189	165	495
3.5	Crater	114	168	270
4	Crater	68	170	125
4.5	Crater	41	172	50
5	Camouflet	25	0	20

This calculation tool and the BEM computer program are described in detail in HNC-ED-CS-S-97-7, Revision 1, "Buried Explosion Module (BEM): A Method for Determining the Effects of Detonation of a Buried Munition" [8] "The procedures in the reference for deciding public and operation withdrawal distances during ordnance and explosives (OE) operation involving intentional detonations are approved" by DDESB on November 3, 1998.

FRAGMENT MITIGATION USING SANDBAGS

USAESCH sponsored a test program in 1997 and 1998 to evaluate the use of sandbag enclosures for mitigating fragments and blast pressures from intentional detonations. Southwest Research Institute (SwRI), under contract to USAESCH, performed a two phase test program of sandbag enclosures. In phase one, the preliminary explosive test phase, four tests on a 155-mm projectile were performed to refine and optimize the test procedure. In phase two, a total of fourteen tests with five different munitions were performed to determine the thickness of sandbags required to capture all primary fragments. Measurements were made of the overpressures at various distances, sandbag throw distances, depth of fragment penetration into sandbags, and noise levels. High-speed film cameras and video cameras were used to visually record the events. Results of these tests are shown in Table 3.
The test results have been used to develop guidelines for the use of sandbag enclosures for intentional detonations. The guidelines include the required sandbag thicknesses to completely

capture primary fragments from the round, the configuration and construction of the sandbag enclosures, and required PSD. The PSD is the greater of the sandbag throw distances or 200 feet. The guidelines permit interpolation between the tested rounds to determine sandbag requirements for any other round, up to the maximum of the 155-mm M107. For any non-tested round, the maximum fragment weight and velocity, and the corresponding kinetic energy, are computed. This is compared to the kinetic energies for the maximum fragments of the tested rounds. The sandbag thickness to be used is that provided for the tested round with the next higher fragment kinetic energy. The determination of sandbag throw distance is based on explosive charge weight, in terms of equivalent pounds of TNT. The charge weight of the non-tested round is compared to those of the tested rounds. The predicted sandbag throw distance to be used is that from the round with the next highest charge weight.

Table 3. Required Wall and Roof Thicknesses for Sandbag Enclosures, with Expected Sandbag Throw Distances and Pressures, for Five Tested Munitions

Munition	Charge Weight, Comp B, lb	Required Wall and Roof Sandbag Thickness, in	Expected Maximum Sandbag Throw Distance, ft	Expected Peak Pressure @ 40 feet, psi	Expected Peak Pressure @ 80 feet, psi	Expected Sound Level @ 100 feet, dB
155-mm M107	15.4	36	220	0.18	0.09	115
4.2-in M329A2	8.17 (TNT)	24	125	0.16	0.06	116
105-mm M1	5.08	24	135	0.18	0.08	120
81-mm M374A2	2.1	20	125	0.14	0.05	119
60-mm M49A3	0.43	12	25	0.08	0.03	118

One important feature of the sandbag enclosures is an air gap of 6 inches on all sides of the round to be detonated. This spacing is maintained between the round and the sandbag walls by simply placing the walls 6 inches from the round. The spacing below the roof is created by stacking the sandbag walls to a height 6 inches above the round, spanning the open space with a sheet of plywood, and then building the roof on top of the plywood. The 6-inch air gap is designed to ensure that the fragments from the round strike the sandbags before the shock wave. The fragments, therefore, penetrating undisturbed sandbags.

A typical sandbag enclosure is shown in Figure 2. This is an enclosure for an 81-mm M374-series mortar. The nominal dimensions of the sandbag pile are 55 inches width by 73 inches long by 30 inches tall.

The results of the test program and the guidelines for the use of sandbag enclosures for intentional detonations are detailed in HNC-ED-CS-S-98-7, "Use of Sandbags for Mitigation of Fragmentation and Blast Effects Due to Intentional Detonation of Munitions" [9]. This report "has been reviewed with respect to explosives safety criteria. The site plan addresses the use of sandbags, IAW reference" HNC-ED-CS-S-98-7 "to mitigate hazards and protect personnel from intentional detonations of munitions up to the 155-mm M107. Based on the information furnished, the proposed use of sandbags for intentional detonations at ordnance and explosives (OE) sites, IAW reference" HNC-ED-CS-S-98-7 "is approved." This approval was given by the DDESB on 23 February 1999.

Figure 2. Sandbag Enclosure for 81-mm M374 Mortar

BARRICADES FOR MITIGATION OF FRAGMENTS IN CASE OF ACCIDENTAL DETONATION

USAESCH has developed several barricades for use during intrusive work on OE sites. These barricades are intended to defeat the primary fragments due to an accidental detonation. The barricades are not intended to reduce the blast pressures, and the barricades do create secondary fragments. Therefore, use of the barricades does not eliminate the need for a withdrawal distance. Also, the barricades are not designed to be reusable after a detonation, so they are not to be used for intentional detonations of OE.

The most frequently used barricade is the Miniature Open Front Barricade (MOFB), more commonly known as the "Bud Light." The MOFB consists of 1/4-inch thick aluminum plates welded together to form a basic, box-shaped barricade, with aluminum channels to hold additional plates in place on the sides and roof. Internally the MOFB is 3 feet wide by 3 feet tall in the front, sloping to a height of 1.5 feet in the rear (see Figure 3). The front-to-rear internal dimension is 3 feet. The basic barricade is designed to be assembled in the shop and carried, fully assembled, to the site. The additional plates must be added at the site and removed prior to relocating to the next site. The basic barricade weighs approximately 100 pounds, with each additional 1/4 inch of aluminum plates adding another 100 pounds. The required total thickness of aluminum is based on the maximum fragment weight and velocity for the most probable munition (MPM) for the site.

Since the MOFB is open at the front, it defeats primary fragments in three directions. The MOFB is not designed for use as an engineering control for an intentional detonation. The MOFB is not designed to mitigate effects from blast overpressure and noise. The MOFB is not intended for reuse after an incident.

Figure 3. Miniature Open Front Barricade

It is the policy of the Ordnance and Explosives Center of Expertise (OE-CX) that the Public Withdrawal Distance for intrusive work shall never be less than 200 feet. The largest munition that the MOFB was designed for is the 81 mm M374 mortar. Several tests have been run with the 81 mm M374 mortar in various orientations to determine the maximum distance that secondary fragments from the MOFB will travel in case of an accidental detonation. The maximum distance that panels from the MOFB were thrown during these tests is 140 feet. Since this is less than the minimum required PWD of 200 feet, the PWD for the sides and rear of the MOFB is 200 feet. The PWD at the front of the MOFB is the maximum fragment distance of the MPM for the site.

The design of the miniature open front barricade is detailed in HNC-ED-CS-S-98-8, "Miniature Open Front Barricade" [10]. This design was approved with the following qualifications by the DDESB on 23 February 1999. HNC-ED-CS-S-98-8 "has been reviewed with respect to explosives safety criteria. Based on the information furnished, the Miniature Open Front Barricade (MOFB) is approved for use, IAW references" HNC-ED-CS-S-98-8, HNC-ED-CS-S-98-1, and HNC-ED-CS-S-98-7 "during intrusive ordnance and explosives (OE) removal operations as defined below."

> "An 'intrusive operation', as used herein, involves an OE item that is partially buried. This approval letter and the MOFB only apply to those excavation operations required to decide if the OE is to be detonated in place or moved to another location. Neither the MOFB nor this approval letter is applicable for intentional detonations or movement of the OE to another location.
> Table 1 of (HNC-ED-CS-S-98-8) contains a list of munitions for which the primary and secondary fragment characteristics of the MOFB has been verified. The MOFB may be used with munitions other than those listed in Table 1 provided the appropriate analyses detailed in references (HNC-ED-CS-S-98-1, HNC-ED-CS-S-98-7, and TM 5-1300) are performed. The MOFB:
>
> a. is intended to defeat primary fragments to its sides, rear, and top for an unintentional detonation;
>
> b. does <u>not</u> mitigate primary fragments to its open front;
>
> c. is <u>not</u> intended to mitigate overpressure or noise from an unintentional detonation;
>
> d. will <u>not</u> be used for munitions with a TNT-equivalent, NEW exceeding 2.3 pounds. [TNT equivalencies may be based on ratios of heats of detonations as detailed in reference (TM 5-1300).]
>
> e. will <u>not</u> be used for intentional detonations; and
>
> f. will <u>not</u> be reused after a detonation."

There are several other barricades for use during intrusive work that are described in HNC-ED-CS-S-96-8, Revision 1, "Guide for Selection and Siting of Barricades for Selected Unexploded Ordnance" [11]. Methods for selecting and siting an appropriate barricade for the individual site are detailed in this report. A detailed report of the design approach and complete fabrication drawings are being prepared for each barricade. As these design reports are completed, they will be submitted for safety approval and added to the OE Toolbox.

ON-SITE DEMOLITION CONTAINER

USAESCH has designed, fabricated and tested an On-site Demolition Container (ODC) for use in destroying unexploded ordnance. The ODC provides an alternative to either open detonation or transportation of recovered ordnance to a remote site for disposal. The container can be used to intentionally detonate small ordnance items, generally ranging in size up to the 81 mm mortar shells. The explosive charge weight limit, including any initiating charge, is 6 pounds TNT equivalent. The container captures all of the shock overpressures and fragments from the explosion. No measurable shock pressure leaves the container. Noise levels at the container are limited to less than 93 dB at a range of 75 feet. The container is designed to be used for a virtually unlimited number of detonations.

The ODC is intended for use at OE sites where munitions can be rendered safe and moved, but where open detonation is not an acceptable method due to proximity of persons or property, or where transportation of ordnance to remote sites is impractical or not economically feasible.

The ODC is a cylindrical steel container with semi-elliptical end caps, oriented vertically, and mounted on an integral support frame and working platform (see Figure 4). Inside the container, an innovative system of different materials is used to capture fragments. This system includes a layer of sand surrounding the ordnance item(s) to be destroyed, a set of steel cable blasting mats, and a segmented inner steel liner. Water bags, at a ratio of five pounds of water for each equivalent pound of TNT, are used to reduce quasistatic pressures. Obviously, parts of this system are damaged in each detonation. The water bags, sand layer and its container will need to be replaced after each shot. The cable mats are expected to be reusable for eight to ten shots. The inner steel liner may last as long as 30 or more shots before it must be replaced. The outer shell should experience no damage from pressures or fragments, and should have a virtually unlimited life.

The ODC was developed using a combination of design and testing. The design was accomplished using widely accepted concepts for explosives safety design. Tests were performed to evaluate the individual candidate materials and the overall concept. These tests were instrumental in refining the design. One complete ODC, including all blast and fragment mitigating materials and the support frame and work platform, has been constructed. This container was subjected to a single proof test using actual fragmenting munitions and a total charge of 6 pounds TNT equivalent. The ODC successfully captured all fragments, eliminated near-field shock pressures, and reduced noise levels to less than 93 dB at a range of 75 feet.

The ODC is detailed in HNC-ED-CS-S-97-3, Revision 1, “Safety Submission for On-Site Demolition Container for Unexploded Ordnance” [12]. The ODC has been approved by the DDESB on 15 September 1998 for intentional detonations that satisfy the following conditions:

> “a. Procedures specified in Technical Report CEHNC-ED-CS-S-97-3-Revision 1, “Safety Submission for Onsite Demolition Container for Unexploded Ordnance,” (April 1998) are to be followed.

The maximum net explosives weight (NEW) to be detonated is six (6) pounds, TNT equivalent material.

The minimum withdrawal distance for related personnel during a detonation is 75 feet.

The minimum withdrawal distance for unrelated personnel and the public is the applicable Inhabited Building Distance (IBD). The required IBD distance will likely result from operations leading up to an intentional detonation when ordnance and explosives are outside the ODC and fragments must be considered. The minimum IBD used will equal or exceed 75 feet.

Site-specific explosives safety site plans must be processed for actual operations of the subject ODC."

Figure 4. On-Site Demolition Container

MAPPING EXPLOSIVES SAFETY HAZARDS (MESH)

USAESCH is developing software to aid in preparation of explosives safety site plans and determination of withdrawal distances for OE sites. Mapping Explosives Safety Hazards (MESH) is an integrated software system that predicts explosion effects from conventional and chemical ordnance and displays hazard distances on a site map. MESH is essentially a simple geographical information system (GIS). Both the input to the analysis software and the output are integrated with and displayed on a computerized map of the OE site. MESH predicts blast effects using either existing software or new programs that use accepted and approved methodologies. Blast effects that MESH can predict include blast overpressures, primary fragments, and chemical agent dispersion. Also, MESH can model the reduction of fragment hazards due to buried explosions. Input from the user includes the types and locations of ordnance on the site and specification of the desired blast effects. MESH outputs include a graphical display of hazard distances on the site map. This display permits the user to easily identify possible threats to personnel and property, and determine where engineering controls may be required. A typical MESH output screen is shown in Figure 5.

MESH uses the Microstation computer graphics program as the graphical user interface. It is structured as a set of blast effects prediction modules linked together in Microstation. Data is input by the user via a set of palettes which activate windows or dialog boxes on the screen. Specific input is done with a combination of mouse clicks and keyboard input. Each dialog box has associated on-line, context-sensitive help.

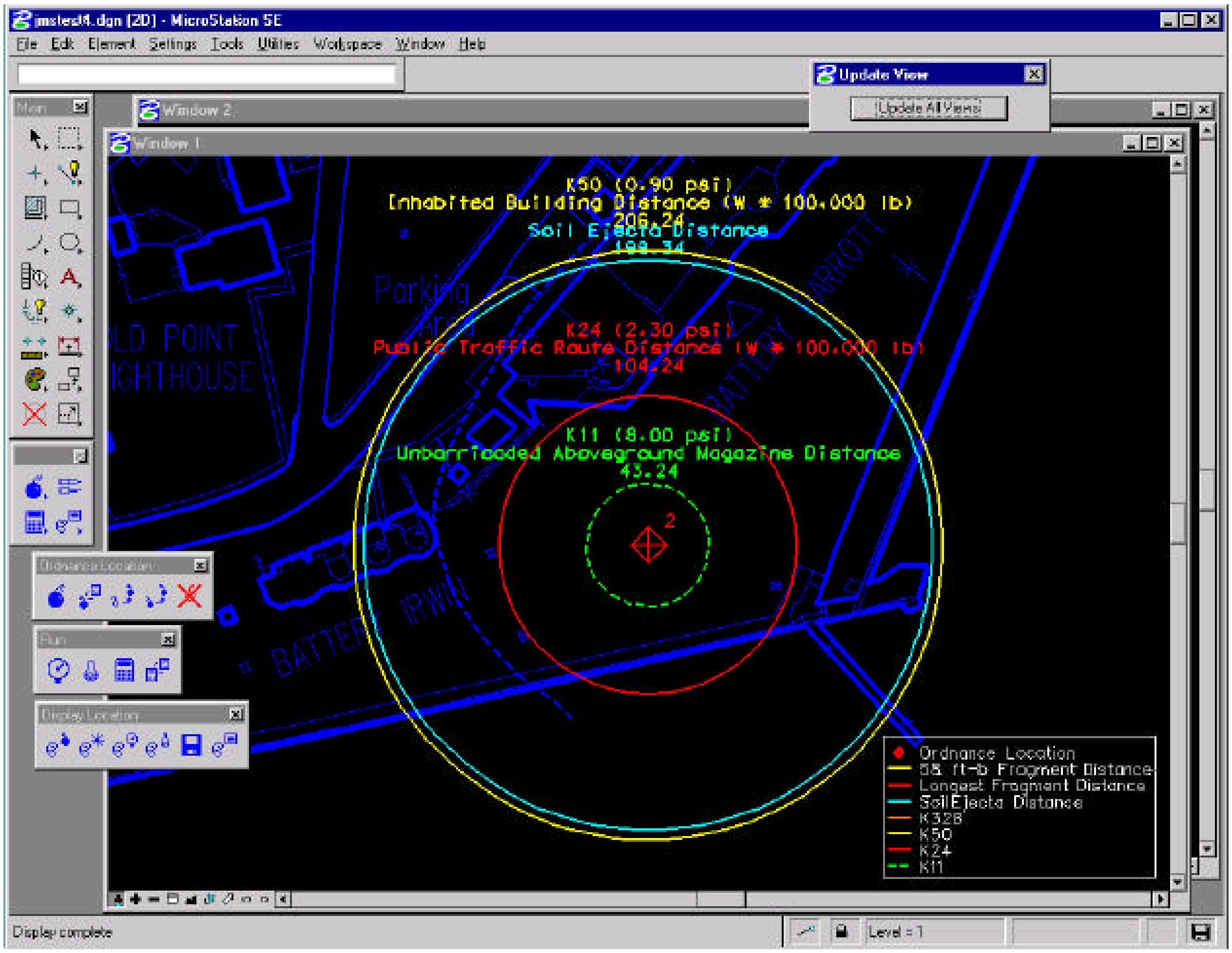

Figure 5. Typical MESH Results Screen

Blast overpressures are predicted by MESH in accordance with the methods in TM 5-1300. The user can select standard overpressures, such as K328 or K50, or enter specific pressure levels of interest. Ordnance fragmentation distances displayed include the maximum fragment distance, computed in accordance with HNC-ED-CS-S-98-1, and the hazardous fragment distance as defined in HNC-ED-CS-S-98-2. Chemical agent dispersal is computed using the D2PC program. For buried explosions, BEM is used to determine the reduced maximum fragment distance and the soil ejecta distance.

MESH has recently been revised by Montgomery Watson, USAESCH's GIS contractor. Changes include improvements in the user interface and revision of the blast effects computation to match current technology and OE policy. Version 3.02 of MESH is expected to be available for distribution in late May 1999. More complete details on the current status of MESH can be found in the companion paper, "Mapping Explosives Safety Hazards (MESH) in a GIS Environment: A Program Update," in the proceedings for the 1999 Global Demilitarization Symposium [13]. MESH has not yet been submitted to DDESB for safety approval. However, since MESH uses approved methods for predicting explosion effects, we anticipate that it will be approved by DDESB for use in explosive safety site planning at OE sites.

VIRTUAL TOOLBOX LOCATION

The virtual location for the OE Toolbox is the Huntsville Center's Internet home page, located at www.hnd.usace.army.mil. Visit the home page and click on Product Lines, Ordnance and Explosives, Technology, Analytical Tools. This site contains the USAESCH technical reports for all of the items in the OE Toolbox. Reports are available in portable document format (PDF). Visitors to the site can download both the reports and the associated software. Access to the Toolbox is password controlled. First-time visitors must provide their name, organization, location, telephone number, e-mail address, a user name and password, and a brief justification for access to the reports. The password is generally activated by the next business day.

CONCLUSIONS

The OE Toolbox provides a set of tools that are effective in enhancing and ensuring explosives safety at OE sites, for both site workers and the general public. As more technologies are developed and approved, these will be added to the Toolbox and to its virtual location on the USAESCH web site.

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